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PHYSICAL-CHEMICAL TREATMENT FOR WASTE-WATER

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THE PHYSICAL–chemical treatment system which at present is most advanced in development, and which seems the best is the clarification–adsorption system schematically illustrated in FIG. 1. In this system chemical clarification and filtration are utilized to achieve almost complete suspended and colloidal solids removal. With a high enough dose of the proper chemicals essentially complete phosphorus removal can also be obtained. The function of the activated carbon step is the removal of soluble organics. As in any conventional system preliminary screening, grit removal and final disinfec-

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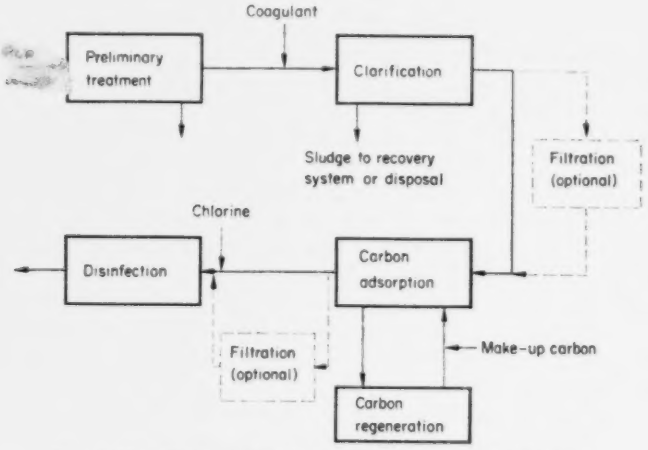

FIG. 1. Flow diagram of a physical–chemical treatment system.

This system does not provide ammonia or nitrate-nitrogen removal. Physical–chemical methods for soluble nitrogen removal are covered in another lecture of this symposium. Any of these nitrogen removal methods can be integrated into the clarification–adsorption system.

CHEMICAL CLARIFICATION

Chemical clarification provides the bulk of the pollutant removal achieved by this type of treatment system. Chemicals which have been successfully used to clarify

raw sewage include organic polymers (RIZZO and SCHADE, 1967), iron salts (WEBER *et al*, 1970), aluminium salts (HANNAH, 1971), and lime (VILLIERS *et al.*, 1970; BISHOP *et al.*, 1970). The inorganic coagulants have the advantage of providing for phosphorus removal. At present there is no rational method for predicting the dose of chemical required. For planning purposes, jar tests are suggested. Fortunately field control of the coagulant dose is possible. For all coagulants except lime the suggested method is monitoring of the clarifier effluent turbidity. Monitoring of phosphorus also appears promising, as good clarification is always obtained when sufficient chemical is added to provide good phosphorus removal. With lime as the coagulant excellent control is obtained by pH measurement. The pH required to achieve good clarification and phosphorus removal is dependent on the chemical characteristics of the sewage. In areas where the alkalinity and hardness are low the high lime process in which the pH is raised to approximately 11.5 is required. Generally, two-stage precipitation with intermediate recarbonation is utilized. In hard water, high alkalinity areas a low lime single-stage precipitation at pH 9.5–10 is sufficient.

TABLE 1 illustrates the treatment obtained with chemical clarification in pilot plants at a variety of locations.

TABLE 1. ACHIEVEMENTS OF CHEMICAL CLARIFICATION

Plant	Chemical	Organic removal (%)	SS removal (%)	P removal (%)
Ewing-Lawrence	170 mg l^{-1} $FeCl_3$	80	95	90
New Rochelle	Lime pH 11.5	80	98	98
Westgate, Va.	125 mg l^{-1} $FeCl_3$	70	—	—
Salt Lake City	80–100 mg l^{-1} $FeCl_3$	75	—	80
Blue Plains	Lime pH 11.5	80	90	95

Sludge disposal plays a dominant role in the economics of any chemical clarification system. Only limited data on the characteristics of sludges resulting from the chemical treatment of raw sewage are available. The data obtained indicate that with iron or aluminum salts as coagulants the resulting sludge volume sometimes exceeds and sometimes is less than primary sludge from the same sewage, and that the chemical sludge is more difficult to dewater in a vacuum filter than the corresponding primary sludge. However, with lime as the coagulation chemical dewatering is extremely rapid just by gravity thickening.

Lime is the only coagulation chemical which can be economically recovered. Recalcining the lime sludge in a furnace has been successfully conducted in a tertiary plant at South Lake Tahoe. The organic solids are incinerated thereby accomplishing ultimate disposal of the sludge. For these reasons it is anticipated that lime will be the coagulant of choice for most situations.

Design criteria for the coagulation equipment is similar to that used in water treatment plants—a flash mix of 1 min, flocculation for 15–30 min and sedimentation at upflow rates of 0.5 and 1.0 gpm^{-1} ft^{-2}.

CARBON ADSORPTION

The total organic removal achieved by the combination of clarification and carbon adsorption at several physical–chemical pilot plants shows that not only is the removal

achieved quite high (95 per cent +) but equally important the residual organics after treatment are quite low. These effluents are superior to the usual quality of secondary effluent (TOC ≈ 20 mg l^{-1}. COD ≈ 40–50 mg l^{-1}).

The results reported from four works showed a removal of organic matter of 95–98 per cent giving rise to effluents containing 3–11 mg l^{-1} TOC. Granular carbon was used. In such systems the waste is passed either upward or downward through columns containing the carbon. Downflow columns function as packed beds and accomplish filtration of the wastewater. Flow rates of 2–8 gpm ft^{-2} have been employed. In this flow range essentially equivalent adsorption efficiency is obtained provided the same contact time is employed. At flow rates below 2 gpm ft^{-2} adsorption efficiency is reduced, while at flow rates above 8 gpm ft^{-2} excessive pressure drop takes place. Contact times employed are in the range of 30 to 60 min on an empty bed basis. In general increases in contact time up to about 30 min yield proportionate increases in organic removal. Beyond 30 min the rate of increase falls off with increases in contact time and at about 60 min contact becomes negligible. Carbon beds to be operated at the lower end of the flow rate range are generally designed for gravity flow. Those systems designed for the higher flow rates employ pressure vessels. A pressure vessel is more expensive to construct than a gravity flow vessel but it requires less land area, and provides greater ability to handle fluctuations in flow rate.

Provision must be made to periodically backwash downflow carbon beds because even if they are preceded by a filter they gradually collect suspended solids. In addition, biological growth takes place on the carbon granules and tends to clog the bed. It is advisable to include a surface wash and air scour to be assured of removal of the gelatinous biological growth. Backwash of the carbon beds satisfactorily relieves clogging but does not completely remove the biological growth.

The latest carbon contacting scheme to be applied to waste treatment utilizes powdered carbon (particle size below 200 mesh). This procedure provides for a mixture of a carbon slurry and the wastewater in a Reactor-Clarifier. Polymer addition is generally required to achieve a good gravity separation of the carbon from the wastewater following contact. The potential advantages of this system are the use of a cheaper carbon (10¢ per pound vs. 30¢ per pound for granular carbon) and a simpler type of contacting system.

In order to provide a good effluent and utilize most of the available capacity, countercurrent contact is required. An alternate arrangement which is used in some plants provides parallel flow through a number of identical contactors.

The factors which must be considered in designing any carbon removal system are the type of carbon contact time, flow rate, series or parallel operation, flow direction, hydraulic considerations and organic capacity. Pilot plant operation shows that the carbon capacity varies from 0.15 to 0.3 lb TOC removed per 1 lb of activated carbon, or from 0.4 to 0.6 lb COD removed per lb of activated carbon.

A carbon requirement at this level would be prohibitively expensive if regeneration and reuse of the exhausted carbon were not possible. At present a technically and economically feasible method is available for the regeneration of granular activated carbon. This method requires heating of the carbon in a multi-hearth furnace in the presence of steam to ≈1750°F. The overall loss expressed as percent of weight of virgin carbon required to restore the total original capacity of the batch ranges from 5 to 10 per cent.

DESCRIPTION AND PERFORMANCE OF SOME PHYSICAL-CHEMICAL PILOT PLANTS

Ewing–Lawrence (WEBER *et al.*, 1970)

For the last several years FMC Corporation has been conducting studies of physical–chemical treatment at the Ewing–Lawrence Treatment Plant near Princeton, N.J. Coagulant is added to the settled sewage, the coagulated solid removed by settlement, and the organic matter removed by adsorption. The results are shown in Fig. 2.

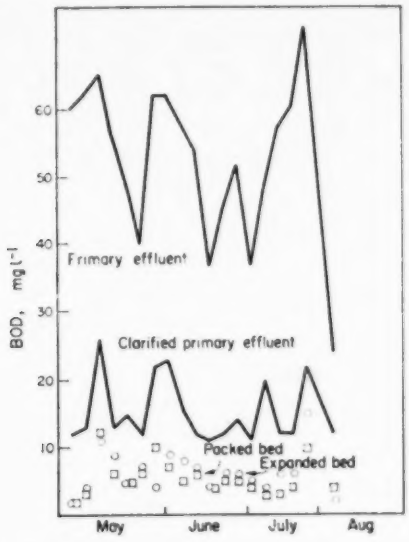

FIG. 2. Removal of BOD by chemical clarification and activated carbon. (FIG. 5 of original paper.

Blue Plains (BISHOP *et al.*, 1970)

At the Blue Plains treatment plant in Washington, D.C., a pilot physical–chemical treatment system is being operated as part of a joint effort of EPA and the District of Columbia. Lime and ferric chloride are the coagulants. The filtered effluent is further purified by ion exchange and carbon adsorption. The flocculation stage of the plant has a capacity of 100,000 gal day^{-1}. The filtration, ion exchange and downflow two-stage carbon beds have a capacity of 50,000 gal day^{-1}.

FIGURE 3 illustrates the treatment performance obtained at this plant for a variety of pollution control parameters. The average quality of the effluent was TOC 6 mg l^{-1}, BOD 5 mg l^{-1}, COD 13 mg l^{-1}, suspended solids 5 mg l^{-1}, phosphorus 0.15 mg l^{-1}, total N 4.6 mg l^{-1}.

Rocky River, Ohio (RIZZO and SCHADE, 1967)

Several studies have been made utilizing polymer addition to existing primary plants followed by small-scale pilot carbon adsorption. One such study was done at the 10 mgd primary facility at Rocky River, Ohio. An anionic polymer was added to

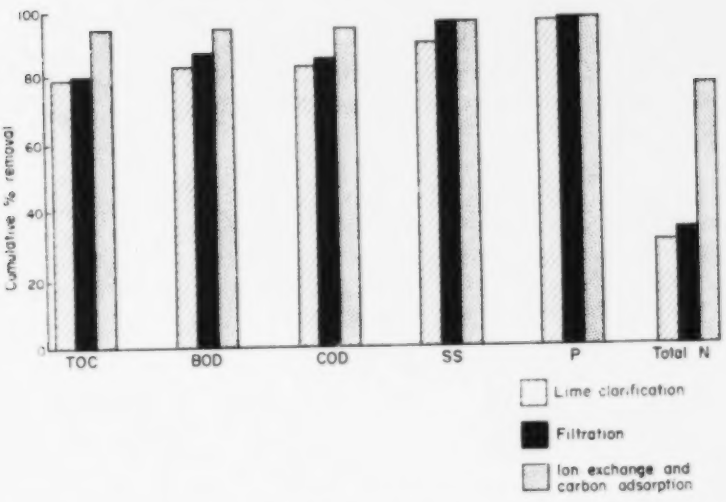

FIG. 3. Removal efficiencies physical–chemical treatment Blue Plains pilot plant.

the existing primary clarifier at a dosage of 0.3 mg l^{-1}, and a side stream of clarified effluent was applied to small carbon columns for a period of about one month. Polymer clarification reduced the suspended solids from 107 to 65 mg l^{-1} the BOD from 118 to 57 mg l^{-1} and the COD from 235 to 177 mg l^{-1}. Carbon treatment further reduced the suspended solids to 1 mg l^{-1} and BOD to 8 mg l^{-1}.

COST ESTIMATES

One of the uncertain factors concerning physical–chemical treatment is the cost of the process. Definitive data will not be available until large-scale plants have been built and are in operation for several years. SMITH (1971) has taken the available information from pilot plants and preliminary designs of several proposed large-scale plants and has made cost estimates for various size plants referenced to October 1970. Amortization was 6 per cent for 24 years. These are presented in TABLE 2. Note that ranges are given for each plant size. These ranges represent the spread of data available.

TABLE 2. PRELIMINARY COST ESTIMATE PHYSICAL–CHEMICAL TREATMENT
(total amortization + O&M, cents per 1000 gal)

Plant size, mgd	5	10	100
Chemical clarification*	9.5–9.6	7.3–9.6	4.0–5.3
Carbon adsorption	11.5–18.0	9.1–13.5	4.5–7.8
Filtration	2.9–4.5	2.1–3.3	1.0–1.4
Total	23.9–36.0	18.5–26.4	9.5–14.5

* Two-stage lime recalcination of sludge.

As a comparison Smith's estimate for primary and secondary treatment with sludge incineration is 16.5 cents per 1000 gallons at the 10 mgd level. With the addition of single stage lime for phosphorus removal the cost would rise to 23.5¢ per 1000 gal which is essentially the same as physical–chemical treatment.

FUTURE DEVELOPMENTS

As a result of the advantages of physical–chemical treatment discussed above and the favorable economic comparison, a number of full-scale treatment plants are being planned or designed. The plants at Rocky River and Painesville, Ohio, will receive Federal research funds. Others are being planned with no expectation of Federal funds other than the normal construction grant.

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